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REMR Management Systems— Coatings for Use on Wet or Damp Steel Surfaces

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Preface

This study was authorized by Headquarters, U.S. Army Corps of Engineers (HQUSACE), as part of the Electrical and Mechanical problem area of the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program. The work was performed under Civil Works Research Work Unit 32798, "Paint Systems for Damp Surfaces." This work unit concluded at the end of FY94. Monitoring of the performance of the field applied systems was conducted under Civil Works research unit 31205, "Development of High Performance Paint Systems." Mr. Alfred D. Beitelman, U.S. Army Construction Engineering Research Laboratories, is the Principal Investigator, and Mr. John A. Gilson (CECW-EE) is the REMR Technical Monitor for this work.

Dr. Tony C. Liu (CERD-C) is the REMR Coordinator at the Directorate of Research and Development, HQUSACE. Dr. Liu and Mr. Harold C. Tohlen (CEEC-ED) serve as the REMR Overview Committee. Mr. William F. McCleese, U.S. Army Engineer Waterways Experiment Station, is the REMR Program Manager. Mr. Beitelman is the Problem Area Leader for the Electrical and Mechanical problem area.

This work was performed by the U.S. Army Construction Engineering Research Laboratories (USACERL) under the general supervision of Dr. Simon S. Kim, Chief of the Maintenance Management and Preservation Division (FL-P), Facilities Technology Laboratory (FL), USACERL. Portions of the laboratory work were conducted by Dr. Mary McKnight, National Institute for Standards and Technology; Ms. Valerie Sherbondy, KTA Tator, Inc., and Dennis Huffman, USACERL. The USACERL technical editor was Gordon L. Cohen, Technical Information Team.

COL James A. Walter is Commander of USACERL, and Dr. Michael J. O'Connor is Director.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
feet	0.3048	meters
inches	0.0254	meters
square ft	0.0929	square meters
mils	25.4	microns

1 Introduction

Background

The Corps of Engineers is responsible for maintaining many steel structures that are under conditions of constant condensation. Many of these structures are located inside locks and dams. Examples include gates, reservoir outlets and their gate recesses, piping systems inside dams, and valves on locks that are difficult to remove from their recesses. These surfaces can normally be blast-cleaned to a white metal grade, but the condensation and/or spray of water from leaking seals causes the surface to immediately become too wet for the application of many coatings. Recent developments in the coatings industry have produced coatings that are advertised to be capable of providing acceptable adhesion to damp and wet steel and to provide a high level of corrosion protection. There are several mechanisms by which these coatings adhere to the substrate: two-component epoxies can be formulated to displace the water from the surface; moisture-cure urethanes can use small amounts of moisture on a surface to chemically cure the coating; and waterborne vinyl acrylics are available that can be applied to a damp surface and form a coating with low moisture permeability. However, no comparative studies of these products are known to exist.

Objective

The objective of this work was to evaluate proprietary coatings developed and marketed for application to damp or wet steel surfaces and develop a performance specification for civil works applications.

Approach

This research was conducted in three phases. During Phase I a number of proprietary coatings were obtained and tested to determine test methods that would properly simulate the conditions experienced in the field. Phase II evaluated a larger number of coatings using the most suitable test methods identified.

In Phase III, the most promising coatings were applied to field structures in order to validate the laboratory test results.

Based on the findings of this work test methods were modified and a draft Commercial Item Description (CID) was prepared. Five materials were tested according to the draft CID, and 3 were found to meet all of the requirements and were included in the CID as potential sources of supply. The CID is attached at Appendix A. The manufacturers supplying products for this study are listed in Appendix B.

2 Phase I—Evaluation of Test Methods

Selection of Coatings

Candidate coatings were obtained by contacting companies listed in the *Annual Directory of Coatings, Linings, and Floor Toppings* (Technology Publishing Company, Pittsburgh, PA, 1992). Manufacturers were asked if they marketed coatings suitable for application to damp or wet surfaces. Eight coatings were selected. They included two- and three-component epoxies, moisture-cured urethane, alkyd, and waterborne epoxy. Table 1 shows the generic composition of the coatings as well as some of the manufacturer's information provided in the technical data sheets. It will be noted that some of the experimental conditions selected in this study are not included in some of the manufacturers' descriptions of recommended uses. These 'extra' test conditions were selected to represent actual field conditions where the coatings would likely be used, so it was desirable, in this portion of the research, to include coatings that might fail due to such conditions.

Experimental Design

All coatings were applied to 100 x 150 mm (4 x 6 in.) hot-rolled steel panels. The panels were solvent-cleaned and abrasive-blasted to obtain a surface profile of 50 μ m (0.002 in.). The panels were divided into three sets: dry, damp and wet. The dry set of panels had no further treatment before application of the coating system.

The damp panels were solvent-cleaned and exposed to a condensing environment before coating application. The environment was produced by exposing cold panels (4.4 °C [40 °F]) to a 95 percent relative humidity condition for 30 seconds. The amount of water deposited on the surface was estimated by weighing a smooth panel before and after the exposure. The average water deposited on the smooth panel as a result of the process was about 10 μ m thick.

Table 1. Phase I coating systems.

Ctg	Generic Type (Pot life at 25 °C)	Surface Conditions Other Than Damp That Are Listed as Suitable or Not Suitable	Recommendations for Specific Application Methods for Damp/Wet Surfaces	Recommended Dry film Thickness (DFT)	Other Requirements and Information	VOC (with no thinning)
1	Two-component water-borne epoxy (1 hour pot life)	Not on saturated steel surfaces or on surfaces with standing water	None. Generally brush, roller or low-pressure airless spray	No recommended DFT, but spread rate of 2.4-5 m ² /l (100-200 sqft/gal); mass solids-54%	Not to be used where condensation may form on uncured product, or below 45 °F	97 g/l (0.75 lbs/gal)
2	Two-component epoxy (5 hour pot life)	None	None. Generally air and airless spray, brush or roller.	100-200 µm (0.004-0.008 in.)	MIL-P-23236B, Type I and IV, Class 2 approvals	287 g/l (2.4 lbs/gal)
3	Three component epoxy copolymer (45 min. pot life)	Not over standing water	None. Generally spray, brush.	350-500 µm (0.014-0.020 in.)	Cautions user to require surface temperature being at least 5 °F above dewpoint for best results	239g/l (2.0 lbs-gal)
4	One-component alkyd oleoresinous varnish	None	None. Generally spray, brush, or roller.	50 µm (0.002 in.)	Cautions user to require surface temperature being at least 5° F above dewpoint for best results	406 g/l (3.4 lbs/gal)
5	One-component moisture-curing urethane	Not over drops or puddles of water	None. Generally brush, roller or spray	Not stated but gives coverage for 75 µm (0.003 in.)	Application acceptable when humidity is 99%	<420 g/l (3.5 lbs-gal)
6	Two-component epoxy (4 hour pot life)	Wet and immersed	Bush or mitt for underwater, Generally spray.	Minimum 125 µm (0.005 in.) per coat		97.5 % volume solids
7	Two-component epoxy (1-2 hour pot life)	Dripping water	None. Generally airless spray or brush.	150-200 µm (0.006-0.008 in.)	Cautions user to require surface temperature being at least 5° F above dewpoint for best results	96.5 % solids
8	Two-component epoxy (4 hour pot life)	Wet	Brush, roll, or sprayed with back-rolling for damp/wet surfaces	150 µm (0.006 in.)	Relative humidity must be below 85% during application and surface temperature being at least 5° F above dewpoint for best results	149 g/l (1.25 lbs/gal)

The wet panels were solvent-cleaned and wetted with distilled water. Five ml of distilled water was applied to the panel using a syringe. The water was spread over the panel and excess removed using a poly (methyl methacrylate) squeegee. The squeegee was passed over the panel a minimum of three times to remove as much water as possible. The valleys of the abrasive blast profile remained filled with water, but there was essentially no pooling on the surface.

Each coating was applied by brush at nominal laboratory temperature of 21 °C. Panels that were damp or wet were coated in a glove box maintained at 93 percent relative humidity (± 2 percent). The amount of coating needed to coat each panel was calculated, and that volume was dispensed onto the panel from a measured syringe. This material was then brushed out using a brush that had been pre-wetted with paint. Two coatings were too viscous to be applied by syringe, so they were dispensed from a measuring spoon. Brushing was continued on the wet panels until the coating appeared to wet the surface to the greatest extent possible.

Immediately after application each panel was placed in the appropriate curing environment (described below). The coatings were allowed to cure for 7 days before performing adhesion and methyl ethyl ketone (MEK) resistance testing.

The adhesion test was performed according to ASTM D 3359 Method B (cross-hatch adhesion). The distance between scribes was adjusted with coating thickness, as described in Method B. Method A (X cut) was used for coatings that were thicker than 135 microns (5 mils). Results were recorded on the 0–5 scale as specified in the test method, with 5 being the greatest level of adhesion.

The degree of cure was determined using the MEK rub test as specified in ASTM D 4752. Although this method does not apply exclusively to any generic type of paint, its rating scheme is specified for zinc-rich paints. Because the objective of this test was to determine the effect damp or wet conditions had on the performance of each coating, the recorded results compare the test panels to their corresponding control panels cured in dry conditions.

In addition to the above formal tests, each coating was subjectively evaluated for any characteristics (positive or negative) that might be of significance in the anticipated field application. These characteristics included mixing and application properties, pinholes, craters or other defects in the applied coatings, and any effect that might be attributed to the damp or wet application conditions.

To determine the effect of curing conditions, each set of panels (dry, damp, or wet substrates) was divided into three exposures. One set of duplicate panels was allowed to cure for 1 week at dry (standard laboratory) conditions. A second set of duplicate panels was allowed to cure for 1 week in condensing conditions produced in a condensation cabinet as defined in ASTM D 4585. The third set of duplicate panels was allowed to cure for 1 week in a low-temperature high-humidity chamber operated at 10 °C, 90 percent relative humidity.

Test Method Evaluation Results and Discussion

For brush applications the procedures for preparation of the damp and wet panels appeared to be satisfactory. The thin layer of water on the damp panels could be detected by sliding a hard object across the surface and noting the change in appearance. The wet panels appeared nearly uniformly wet when care was taken to remove as much water as possible with the edge of the plastic sheet. However, there was a large difference in the amount of water present using the two procedures.

The procedure for preparing damp panels for spray application testing would need to be revisited. It would be more difficult to maintain the thin moisture layer on the panel during spraying than during brush application. Handling time and air movement in the spray booth would probably allow the dampness to dry before the paint hit the test panels, so the test would be no different than applying paint to a dry panel. Laboratory spray application conditions would also affect the wet test panels, but the effect in the spray booth would be similar to the effect in the field under similar conditions. Therefore, the spray testing of wet panels in the laboratory may be considered a reasonable simulation of similar wet conditions in the field.

No differences could be detected in the ease of applying any of the coatings to damp surfaces versus dry surfaces. In all cases, application of the coatings to wet surfaces was difficult. All the coatings tended to crawl or crater during the initial brush stroke, and many strokes were needed to spread the coatings over a wet surface.

Craters or other defects appeared in the films of some of the coatings soon after application (see Table 1), but no relationships were found between defect formation and the condition of the panel (i.e., dry, damp, or wet). Therefore, it appeared for these coatings that the defects were related to the film-forming properties of the coating materials rather than to panel condition. The possible

effect of high-humidity during application on the tendency to form defects was not investigated in Phase I. Additionally, the effect of application procedure on defect formation was also not investigated during Phase I.

The performance results for the coatings in the adhesion and MEK resistance tests after curing for 7 days in one of the three environments are shown in Table 2. As discussed previously, neither of the tests is sensitive to small changes in performance. Although there were a few intermediate adhesion ratings, most ratings were either 5 or 0. That is, the panel or cure condition usually either had *no* effect or a *major* effect, but rarely a *moderate* effect. The differences in MEK resistance were more varied and more difficult to characterize. Whenever the difference between the control specimens and a test specimen was questionable (i.e., too subtle to clearly define), it was reported as no difference. There was also considerable overall variability in MEK resistance among the eight coatings. Their MEK resistances tended to fall into three groups and were classified accordingly. Group 1, noted as H in Table 2, had either no notable effect or, at most, a slight dulling of the film. Group 2, noted as M in the table, typically resulted in the development of a slight depression of the film. Group 3, noted in the table as S, resulted in rapid removal of the film to substrate.

As can be seen in Table 2, few coatings resulted in any detectable differences in adhesion or MEK resistance when applied to damp or dry surfaces and dried at ambient laboratory conditions. Similarly, only a limited number of coatings exhibited a difference in performance when cured in dry or cool environments. However, a significant number of coatings were adversely affected by curing in the condensation environment produced in the ASTM D 4585 chamber. Only two of the eight coatings showed no noticeable effects from any of the exposure conditions.

Phase I indicated that there are coatings available that will adhere to wet steel in a condensing environment. This type of environment is often encountered in Corps of Engineers civil works applications. The most demanding condition in the work performed required the coating to cure in a condensing environment: six of the eight test coatings exhibited some form of adverse effect when applied to wet panels, five of eight were adversely affected when applied to damp panels, and three of eight were adversely affected when applied to dry panels. Curing in a low-temperature, high-humidity environment had little if any effect on most of the coatings. Therefore, it was decided that Phase II work should concentrate on further identifying the coatings that exhibited suitable performance when applied to wet panels and cured in a condensing environment.

Table 2. Phase I results for duplicate test panels.

Substrate Condition Cure Condition	Dry Dry	Dry Conden	Dry Cool	Damp Dry	Damp Conden	Damp Cool	Wet Dry	Wet Conden	Wet Cool
Coating 1 Adhesion	5 5	NA NA	5 5	5 5	NA NA	5 5	5 5	NA NA	5 5
MEK Resist	H H	NA ¹ NA ¹	H H	H H	NA ¹ NA ¹	H H	H H	NA ¹ NA ¹	H H
Coating 2 Adhesion	5 5	5 5	5 5	5 5	5 5	5 5	1 0	0 ² 0 ²	0 0
MEK Resist	M M	M M	M M	M M	M M	M M	M M1	M1 M1	M1 M1
Coating 3 Adhesion	5 5	5 5	5 5	5 5	4 5	5 5	5 5	3 4	4 4
MEK Resist	M M	M1 M	M M	M M	M M	M1 M	M M1	M M1	M M
Coating 4 Adhesion	5 4	5 5	5 5	5 5	4 5	5 5	5 5	4 4	4 5
MEK Resist	S S	S S1	S S1	S S	S S1	S1 S1	S S	S1 S1	S S
Coating 5 Adhesion	5 5	3 3	5 5	5 5	3 0	5 5	5 5	0 0	5 5
MEK Resist	M M	M1 M1	M M	M M	M M	M M	M M	M1 M1	M M
Coating 6 Adhesion	5 5	5 5	5 5	5 5	5 5	5 5	5 5	5 5	5 5
MEK Resist	H H	H H	H H	H H	H H	H H	H H	H H	H H
Coating 7 Adhesion	5 5	5 5	5 5	5 5	5 5	5 5	5 5	5 5	5 5
MEK Resist	H H	H H	H H	H H	H H	H H	H H	H H	H H
Coating 8 Adhesion	5 5	5 5	5 5	5 5	5 5	5 5	5 5	0 -	5 5
MEK Resist	H H	H H	H1 H1	H1 H1	H1 H1	H1 H1	H1 H1	H1 H1	H1 H1

Codes: Substrate Condition (Dry=Dry; Damp=10µm condensed water; Wet=Water fills profile)

Cure Condition (Dry=Laboratory Conditions; Conden=ASTM D 4585; Cool=10°C/90%RH)

Adhesion (ASTM D 3359 test results; NA=Not Applicable, test not performed)

MEK Resist (H=Hard, Solvent may cause slight dulling of the film; M=Moderate, Solvent created depression in the film; S=Softened, Coating was rapidly removed to the substrate; NA=Not Applicable, test not performed; "1" following the rating indicates additional softening in this exposure)

Notes:

Coating 1 = Environmental curing condition outside manufacturer's recommended conditions, coating tended to run off panel. Corrosion rating (ASTM D 610) of 5-6 for all specimens cured in condensing conditions. Small blisters with black corrosion inside formed on specimens cured in wet or damp conditions. Blister density considerably greater on wet panels than damp.

Coating 2 = Some corrosion under film in area of adhesion test. Coating "blushed" in condensing cabinet.

Coating 3 = Corrosion rating (ASTM D 610) of 8-9 for all specimens cured in condensing conditions.

Coating 4 = General corrosion on all specimens cured in a condensing environment; Corrosion rating (ASTM D 610) of 5 for all wet specimens and 7-8 for all damp and dry specimens.

Coating 5 = Coating flattened and whitened and developed a corrosion rating (ASTM D 610) of 9 for all specimens cured in condensing conditions.

Coating 6 = Coating flattened and developed small depressions and a corrosion rating (ASTM D 610) of 9 for all specimens cured in condensing conditions; Material was very viscous.

Coating 7 = Coating surface eroded in condensing environment; Wet specimens exposed in environmental cabinets appeared to have better adhesion than those cured in room environment.

Coating 8 = Corrosion rating (ASTM D 610) of 8-9 for all dry and damp specimens and 6-7 for all wet specimens cured in condensing conditions.

3 Phase II—Laboratory Evaluation of Coatings

Introduction

The results of the Phase I study identified several coatings that appeared to cure in a condensing environment and adhere to steel that was damp or wet before brush application. Because of this tentatively acceptable performance, Phase II of the program was initiated. The objective of Phase II was to further define the test methods and evaluate additional coatings. Spray application of the coatings and two-coat systems was added to the testing matrix.

Experimental Design

Twelve coating systems were obtained for application and evaluation. Evaluation focused on the application characteristics and resistance to immersion or condensation conditions immediately after application. The coating systems were applied to white-metal-blast-cleaned carbon steel test panels that were wetted with fresh tap water. The coatings were applied either by brush or an airless spray system. Immediately after application, the panels were placed either in distilled water or in a condensing humidity cabinet. Twenty-four hours after being put into the test, half of the panels were scribed while the others were left unscribed. The testing was continued for a total duration of 2 weeks. After 2 weeks of exposure, the panels were evaluated for the following properties: adhesion, MEK resistance, blistering, and loss of adhesion at the scribe.

Coating System Selection

As in Phase I, candidate coatings were obtained by contacting companies listed in the *Annual Directory of Coatings, Linings, and Floor Toppings* (Technology Publishing Company, Pittsburgh, PA, 1992). Coating manufacturers were selected from lists that indicated they produced coatings that could be used in wet or damp conditions. The paint manufacturers were contacted by phone

and informed about the testing program. All manufacturers received a copy of the testing protocol that was to be used. Two of the manufacturers contacted declined to participate.

Twelve manufacturers expressed interest in participating in the testing. However, due to time constraints imposed by the scope of work, not all of the interested manufacturers were able to supply paints by the stated deadline. Because two of the manufacturers had indicated they would be interested in testing more than one system, and their paints were received by the deadline, these alternate systems were used in the Phase II tests.

The specific coatings tested in Phase II were chosen by the manufacturers themselves knowing the conditions under which they were to be applied and to which they would be exposed immediately after application. Each manufacturer also recommended the film thickness and the number of coats to be applied.

The 12 systems to be tested included a one-component urethane, 10 two-component epoxies, and one epoxy mastic primer with a two-component urethane topcoat. Three of the products had been tested in Phase I. The generic paint type, along with the number of coats recommended by the manufacturer may be found in Table 3 (which also lists the mix ratio, pot life, the volatile organic content, and the cost per square foot).

Evaluation Procedure

The laboratory investigation consisted of applying each of the 12 paint systems to eight 3 x 9 in. hot-rolled carbon steel panels that had been blast-cleaned to SSPC SP-5 White Metal with a surface profile of 1 1/2 to 2 1/2 mils (ASTM D 4417, Method C) using steel grit. The back side of each panel was painted in a dry condition with the appropriate system using conventional spray equipment and then dried at room temperature. This application was to serve as a control for the test application.

When the front side of each panel was to be painted, the panel was first placed in a pan of water. A squeegee was then used to clear the ponded water from the surface leaving the valleys of the profile filled with water. The wet panels were painted while in the horizontal position to maintain the wet surface. Four panels were painted by airless spray and four were painted by brush. If the system specified was a two-coat system, the primer was applied to the wet steel and placed into the test environment until time for recoating. The topcoat was

Table 3. Phase II coating systems.

Sys	Number of Coats	Generic Paint Type	Dry Film Thickness (mils)	Mix Ratio	Potlife	Volatile Organic Content	Cost/sq ft (2000 sq ft area)*
1	2	primer epoxy	4 - 8	4:1	15 min induction 5 hrs at 77°F	2.4 lbs/gal (292 g/l)	\$0.13
		topcoat epoxy	4 - 8	4:1	15 min induction 1 1/2 hrs at 75°F	2.4 lbs/gal (292 g/l)	<u>\$0.13</u>
						Total	\$0.26
2	1	high solids epoxy	8 - 10	1:1	20 min induction 1 1/2 hrs at 75°F	0.24 lbs/gal (28.8 g/l)	\$0.25
3	1	polyamine cured epoxy	8	1:1	2 hrs. at 68°F	1.3 lbs/gal (156 g/l)	\$0.12
4	2	primer - polyamide - adduct cured epoxy	4	3:1	2 hrs. at 68°F	1.3 lbs/gal (156 g/l)	\$0.12
		topcoat - polyamine cured epoxy	6	1:1	2 hrs. at 68°F	3.48 lbs/gal (417 g/l)	<u>\$0.07</u>
						Total	\$0.19
5	2	primer - moisture cured polyurethane	3 - 4	1 comp	N/A	2.8 lbs/gal (336 g/l)	\$0.05
		topcoat moisture cured polyurethane	3 - 4	1 comp	N/A	2.8 lbs/gal (336 g/l)	<u>\$0.03*</u>
						Total	\$0.08
6	1	epoxy	4 - 8	4:1	15 min induction 5 hrs at 77°F	2.4 lbs/gal (292 g/l)	0.13
7	2	epoxy mastic	5 - 7	1:1	4 hrs. at 77°F 1 hour induction	2.83 lbs/gal (339 g/l)	\$0.09
		urethane	1.5 - 2	1:4	4 hrs. at 77°F	3.48 lbs/gal (417 g/l)**	<u>\$0.06</u>
						Total	\$0.15
8	2	glass filled epoxy	5	1:1	15 min induction 4 hrs. at 77°F	0.93 lbs/gal** (111 g/l)	\$0.165
		glass filled epoxy	5	1:1	15 min induction 4 hrs. at 77°F	0.93 lbs/gal** (111 g/l)	<u>\$0.165</u>
						Total	\$0.33
9	2	epoxy/ amine modified polyamide	3 - 8	1:1	8 hours at 70° - 90°F	2.1 lbs/gal (252 g/l)	\$0.13
		epoxy/ amine modified polyamide	10 - 12	1:1	8 hours at 70° - 90°F	2.1 lbs/gal (252 g/l)	<u>\$0.24</u>
						Total	\$0.37
10	1	epoxy co-polymer	14 - 20		45 min at 75°F	2.0 lbs/gal (240 g/l)	\$0.82
11	2	epoxy	8 - 10	2.3:1	50 min at 77°F	0	\$0.35
		epoxy	8 - 10	2.3:1	50 min at 77°F	0	<u>\$0.35</u>
						Total	\$0.70
12	1	amine cured epoxy	20	4:1	1 hr at 75°F	1.47 lbs/gal (176 g/l)	\$0.71

* Note: Cost is for coating materials only, not surface preparation or labor.

applied at the shortest effective recoat time, as specified in the product's technical data sheet. Recoat times ranged from a few hours up to 24 hours, and the panels were dry at the time of recoating. The coatings were applied during July and August at ambient conditions in a paint room, with temperatures ranging from 75 to 90 °F and a relative humidity ranging from 49 to 75 percent. The exact conditions for each paint application may be found in Table 4. Observations noted during the painting procedure as well as the dry appearance before testing are shown in Table 5.

Immediately after application of the final coat, two of the spray-applied panels were immersed in a container of distilled water and two others were placed in a condensing humidity cabinet in accordance with ASTM D-4585, *Practice for Testing Water Resistance of Coatings Using Controlled Condensation*. The same procedure was followed for the brush-applied panels. After 24 hours of exposure, 1 of each application in each exposure was scribed with a diagonal line 2.5 in. long. Immediately after scribing, each panel was replaced in its appropriate test chamber.

Table 4. Phase II coating application conditions.

System	Coating	Back (Control)	Front
1	Primer	78°F/67%	78°F/60%
	Topcoat	84°F/62%	75°F/54%
2	Single Coat	80°F/75%	82°F/55%
3	Single Coat	80°F/61%	80°F/72%
4	Primer	80°F/68%	76°F/74%
	Topcoat	80°F/61%	76°F/66%
5	Primer	80°F/75%	78°F/60%
	Topcoat	77°F/71%	75°F/54%
6	Single Coat	90°F/58%	80°F/61%
7	Primer	80°F/68%	78°F/60%
	Topcoat	80°F/61%	78°F/60%
8	Primer	80°F/68%	78°F/60%
	Topcoat	80°F/61%	78°F/66%
9	Primer	80°F/68%	78°F/60%
	Topcoat	80°F/61%	76°F/66%
10	Single Coat	84°F/49%	78°F/68%
11	Primer	84°F/49%	78°F/60%
	Topcoat	84°F/49%	76°F/66%
12	Single Coat	90°F/58%	80°F/61%

Table 5. Notes on application and dry film appearance for Phase II.

System	Application	Appearance after Cure
1	Application was unaffected by the presence of water.	Brush marks indicate poor flow.
2	Pot life is extremely short if conditions are warm (>90°F).	Good flow properties, no visual differences between the brush and spray application.
3	Brush application difficult due to drag over the wet surface. This caused uneven coverage.	Brush marks indicate poor flow.
4	Orange peel upon application of both the control and wet side of the panels.	Brush marks and orange peel indicate poor flow.
5	Primer application was unaffected. Topcoat pinholed upon application. Drips and sags occurred at low film builds.	Uneven due to drips, sags, and pinholes.
6	Brush application was hindered by slight drag of the paint, coverage was still obtained.	Brush marks indicate poor flow.
7	The paint sagged with minimal changes in the wet film thickness.	Brush marks indicate poor flow. Color variations were evident due to thickness differences.
8	Application was unaffected by the presence of water.	Brush marks and texturing indicate poor flow of both types of application.
9	Application was unaffected by the presence of water.	Brush marks displayed by the topcoat indicate poor flow.
10	Application was unaffected by the presence of water.	Good flow properties, indicated by little visual difference between brush and spray application.
11	Application was unaffected by the presence of water.	Good flow properties, indicated by no visual difference between brush and spray application. No sag, even at high film build.
12	Brush application was hindered by drag, coverage was still obtained.	Brush marks indicate poor flow.

Two weeks after the panels were initially placed in the test chambers, they were removed to evaluate MEK resistance, adhesion, adhesion at the scribe, and blistering or other visual changes. A tabulation of these results may be found in Table 6.

MEK Resistance

The resistance to MEK was determined by applying MEK to a cotton Q-tip and rubbing the surface. The procedure used was similar to ASTM D-4752, *Test Method for Measuring MEK Resistance of Ethyl Silicate (Inorganic) Zinc-Rich Primers by Solvent Rub*. The MEK resistance was rated by the amount of color transfer that occurred during testing and by any softening of the paint in the tested area. The color transfer was rated as either high, moderate, or slight after a duration of 50 double rubs. If the coating was removed in 50 double rubs or less, a notation to that effect was added to the comment section of the records. In

Table 6. Tabulated results for Phase II testing.

Sys	Exposure (H)	Application (SIB)	MEK		Adhesion		Blister		Adhesion @Scribe	Comment
			Color	Hard	A	B	A	B		
1	I	S	H	S	4A	5A	10	10	---	
	H	S	S	H	4A*	4A*	10	10	None	Uneven surface; *Poor intercoat adhesion
	I	B	H	S	4A*	5A	10	10	None	*Poor intercoat adhesion
	H	B	S	H	4A*	4A*	10	10	None	Craters on surface; *Poor intercoat adhesion
2	I	S	H	H	5A	5A	4F	4F	1/8"	Paint soft @ scribe; Failure within paint layer
	H	S	H	H	5A	5A	6M	4MD	1/16"	Paint soft @ scribe; Failure within paint layer
	I	B	H	H	5A	5A	4M	10	1/4"	Paint soft @ scribe; Failure within paint layer
	H	B	H	M	5A	5A	4F	10	1/16"	Paint soft @ scribe; Failure within paint layer
3	I	S	H*	S	0A	0A	2D	2D	∞**	*Metal Visible; **Entire paint film lifted
	H	S	H*	S	4A	0A	2M	2M	0-5/8"	*Metal Visible
	I	B	S	S	*	*	*	*	*	*Entire paint film lifted, could not perform test
	H	B	S	S	5A	5A	10	10	None	
4	I	S	H	S*	5A	5A	10	10	None	*Through to primer in 40 double rubs
	H	S	S	S*	5A	5A	10	10	None	*Surface only softened; Textured surface
	I	B	H	S*	5A	5A	10	10	None	*Through to primer in 25 double rubs; Voids on surface
	H	B	S	S*	5A	5A	10	10	None	*Surface only softened; Textured surface
5	I	S	N	H	4A	4A	10	10	None	
	H	S	N	H	4A	4A	10	10	None	Voids in topcoat, primer visible
	I	B	N	H	4A	4A	10	10	None	
	H	B	N	H	4A	4A	8M	8M	None	Voids in topcoat, primer visible
6	I	S	H	H	1A	5A	10	10	---	
	H	S	N	H	0A	4A	10	10	0-1/16"	
	I	B	H	H	5A	4A	10	10	1/8-1/16"	
	H	B	N	H	2A	0A	10	10	1/16-1/4"	

Table 6. Continued.

Sys	Exposure (I/H)	Application (S/B)	MEK		Adhesion		Blister		Adhesion	Comment
			Color	Hard	A	B	A	B	@Scribe	
7	I	S	H	S	5A	4A	10	10	1/16-13/16"	Loss of gloss; Pinholes
	H	S	H	S	5A	5A	10	10	1/8-1/4"	Pinholes
	I	B	H	S	5A	5A	10	10	1/8-1/4"	Pinholes
	H	B	H	S	5A	4A	10	10	0-1/4"	Loss of gloss
8	I	S	H	S	4A	4A	10	10	None	Few pinholes on surface
	H	S	S	H	5A	4A	10	10	None	Pinholes on surface
	I	B	H	H	5A	4A	10	10	None	Pinholes
	H	B	S	H	5A	5A	10	10	None	Pinholes
9	I	S	M	H	5A	4A	10	10	None	Pinholes
	H	S	M	H	4A	4A	10	8MD	None	Primer disbonding; Streaking & flaking of topcoat
	I	B	M	S	4A	4A	10	10	None	High number of voids
	H	B	M	H	4A	4A	10	10	None	Streaking & flaking of topcoat
10	I	S	H	H	5A	5A	10	10	None	
	H	S	H	S	5A	5A	10	10	None	Loss of gloss
	I	B	H	S	5A	5A	10	10	None	
	H	B	H	S	5A	5A	10	10	None	Loss of gloss
11	I	S	S	H	5A	5A	10	10	None	Pinholes; Loss of gloss
	H	S	N	H	5A	5A	10	10	None	Glossy but marked with drips and streaks
	I	B	S	H	5A	5A	10	10	None	Pinholes; Loss of gloss
	H	B	N	H	5A	5A	10	10	None	Uneven cratering of surface
12	I	S	H	H	4A	4A	10	10	None	
	H	S	N	H	5A	5A	10	10	None	
	I	B	H	H	5A	5A	10	10	None	
	H	B	M	H	5A	5A	10	10	None	

Codes: Exposure (I=Immersion in distilled water; H=ASTM D 4585)
 Application (S= Spray; B=Brush)
 MEK Color (H=High color transfer; M=Moderate color transfer; L=Low color transfer; N=No transfer)
 MEK Hard (H= Hard, unaffected by solvent; S=Softened by solvent)
 Adhesion (ASTM D 3359 test result for duplicate panels)
 Blister (ASTM D 610 test result for duplicate panels)
 Adhesion @ Scribe (ASTM D 1654 test result)

addition to rating the color transfer, a notation pertaining to softening of the coating was also made. This testing was performed by probing the coating with a blunt instrument. If the area exposed to the MEK remained the same as an untested portion, it was rated as hard: any change was noted as softening. If the coating displayed any color transfer or softening, the back (control side) of the panel was also tested to determine if the sensitivity to MEK was characteristic of the paint or attributable to the exposure testing. Although systems 2, 3, and 8 (see Table 3) did exhibit some color transfer when the control application was tested, none of the control applications softened when exposed to MEK (Table 6).

Adhesion

The adhesion was tested on an unscribed portion of the panel and was rated in accordance with ASTM D-3359, *Method for Measuring Adhesion by Tape Test*, Method A. This testing involved cutting an X into the coating system and applying pressure-sensitive tape to the surface. The tape was then pulled from the surface and the area evaluated to determine how much paint was removed. No removal was rated as 5, while removal beyond the cut surface was rated as a 0. The adhesion rating listed is for the adhesion at the metal interface. Any noticeable adhesion differences between coats were noted in the comment section.

Blistering

The blistering of the surface was rated in accordance with ASTM D-714, *Evaluating Degree of Blistering of Paints*. This method rates blistering by both size and frequency. Size is rated on a scale of 0 to 10, with 10 representing no blistering. The frequency is rated as either dense (D), medium dense (MD), medium (M), or few (F).

Scribe Corrosion

In addition to the overall adhesion of the paint to the panel, the corrosion at the scribe was determined by evaluating the paint adhesion at the scribe. This was done in accordance with ASTM D-1654, *Method for Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments*, Procedure A, Method 2. This involved taking a blunt metal instrument and running it across the scribe to determine if the paint could be easily removed. The distance that the paint was removed from the scribe line was recorded. In one case (system 2, a single-coat epoxy system), a portion of the paint layer was removed. A thin layer of the paint remained on the metal surface and there was no sign of corrosion. The failure in this case appeared to be due to softening at the scribe.

Appearance

In addition to the above evaluations, the surface of each panel was rated for any visual changes that may have occurred. In some cases this may have been a loss of gloss or voids that appeared either on the surface or through one of the coats.

Discussion of Phase II Results

After all of the data were collected, the results for each paint system were reviewed to determine if the system might be acceptable for use in field conditions. Acceptability was determined by considering adhesion, MEK resistance, blistering, adhesion at the scribe, and appearance changes.

Acceptable adhesion was defined as ratings of 4A or 5A, indicating little or no removal of paint from the cut area. This was considered significant because some paints did not develop adhesion to a wet surface. A decrease in adhesion indicates that there may be a chance of delamination or rusting under the paint system, and this would be unacceptable in the humid and wet environments that these products are expected to endure.

The purpose of the MEK resistance test was to determine if the coating had reached a complete cure. The paint systems were expected to show no significant difference in MEK resistance between the coating applied under ideal laboratory conditions and one applied and cured under adverse conditions. For this testing, some color transfer was considered acceptable as long as the coating did not soften considerably or exhibit complete removal. Because these panels were placed in immersion or condensing humidity immediately upon being painted, any change in the solvent resistance could be an indication that the cure of the coating was being interfered with by the moist conditions. If a system does not achieve proper cure, its service life probably will decrease.

Blister ratings of 9 to 10 (very small or no blisters) were considered acceptable. Small, infrequent blisters were not considered detrimental to the system as long as good adhesion was also exhibited. If the blisters became larger in size than a 9, it was considered likely that the blistering could continue to increase in size. An increase in blister size and frequency is often associated with a decrease in adhesion and early failure of a coating system.

Adhesion was also rated by probing at the scribe. Given the short duration of the test, any loss of adhesion is of some concern. If the paint could be removed more than 1/8 in. or if the rust had occurred 1/8 in. beyond the scribe, this indicated that the coating either had not developed effective adhesion or it would not withstand wet humid conditions without significant undercutting. Any loss of adhesion at the scribe is significant since it suggests that the coating performance will decrease in service after it has suffered any mechanical damage from abrasion or impacts. In one case, a portion of a test coating was removed due to softening of the paint film, but the metal itself was still protected by a thin layer of coating. Because no rusting had occurred at this area, this level of corrosion protection was considered acceptable.

In addition to the quantitative results, the more subjective factors (e.g., appearance after testing) were also taken into account. In some cases, a change in appearance was caused by degradation of the coating surface, but in other cases it was only a textural change due to water droplets or handling while the coating was still wet. The type of appearance change and its possible causes were taken into account.

The coatings that performed well and would be considered acceptable for this type of application environment were systems 8 (2 coat glass-filled epoxy), and 12 (1 coat amine-cured epoxy). These systems had the best final testing results, with adhesion of 4A to 5A, no blistering, and slight to no color transfer during MEK resistance testing. These same panels showed no loss of adhesion at the scribe.

Coating systems 4 (2 coat polyamide adduct epoxy primer with polyamide topcoat), 10 (1 coat epoxy co-polymer), and 11 (2 coat epoxy) produced less impressive results. All of these systems exhibited adhesion of 5A, no blistering, and no loss of adhesion at the scribe. However, all of them had slight to high color transfer during the MEK resistance testing. The sensitivity to MEK was measured as a change from the cured, control side of the panel. The increase in MEK sensitivity may indicate either incomplete cure of the coating system or degradation of the coating. Both of these conditions may be a result of moisture exposure, and may affect the long-term performance of the paint. System 5 (2 coat moisture-cured urethane) also had impressive performance properties, but was not included among the highest performers because of poor application properties. Water caused the coating to go on very unevenly resulting in drips, sags, and pinholes even at low film builds.

Based on the Phase II results, systems 1 (2 coat epoxy), 2 (1 coat high-solids epoxy), 3 (1 coat polyamide epoxy), 6 (1 coat epoxy), 7 (2 coat, epoxy mastic primer with urethane topcoat), and 9 (2 coat epoxy amine modified polyamide) would not be recommended for the type of applications tested here. System 1 did not appear to develop intercoat adhesion and displayed poor flow properties upon application. System 2 was not included because it blistered on isolated areas of the panel and lost adhesion at the scribe. Coating removal at the scribe was caused by softening and did not lift the entire paint film from the surface. System 3 was the only system to completely delaminate immediately upon immersion of the panels that were brush-painted. In addition, the adhesion after exposure was rated as 0A, the film lifted up to 5/8 in. at the scribe, high color transfer was noted during MEK resistance testing, and the paint would drag when brush-applied to a wet surface. The drag made it difficult to cover the entire panel. System 6 did not appear to develop adhesion to the wet surface as indicated by adhesion results of 1A and 0A. In addition, loss of adhesion at the scribe ranged up to 3/4 in. System 7 displayed high color transfer during MEK resistance testing and showed signs of poor flow and sagging during application. System 9 had the poorest appearance of all systems after testing. The surface layers of the topcoat flaked off, decreasing the life expectancy of the coating. In addition, there was moderate color transfer during the MEK testing and the primer was detaching from the substrate.

Test Method Effectiveness

Analysis of the test data clearly separated the coatings into three distinct performance categories: the best (two products); the middle (four products); and the poorest (six products). Because the tests clearly discriminated coatings on the basis of performance, it is concluded that the test methodology was appropriate for laboratory screening purposes. However, it is believed that refinement of the methodology could make the test conditions even more closely representative of typical field conditions.

Field temperatures in the locations where these coatings are to be applied typically range between 55–60 °F. Because the present testing program was conducted at relatively high temperatures (approximately 115 °F in the Cleveland Condensing Cabinet and approximately 75 °F in the aerated distilled water) it is likely that the laboratory test coatings cured more extensively than those same coatings would cure in actual field service. These temperature differences constituted the main difference between laboratory exposure test conditions and field conditions. It is possible that comparative testing of a duplicate set of panels

in both aerated distilled water at ambient (approximately 75 °F) and field temperatures (approximately 55–60 °F) may provide additional information that would allow for better screening of candidate coating systems.

The only other significant difference between the laboratory test environment and field conditions appears to be that the topcoats in two-coat systems were applied to dry panels in the laboratory, whereas actual field conditions would by definition remain damp or wet during topcoat application. Application of subsequent coats to a primer that has attained a dry condition may give a relative advantage in the laboratory to topcoats which do not have the same water displacement properties as their primers. However, it is not believed that these changes would make a major difference in the test results.

If subsequent laboratory testing were to be performed, it is suggested that all topcoats be applied under the same application and curing conditions as the prime coats.

4 Phase III—Field Evaluation of Selected Coatings

Field Application I

Based on the results of the Phase II study, a contract was let for the application of two of the tested coating systems to a field structure: liners and gates at Lake O' the Pines, located within Fort Worth District at Jefferson, TX.

Each gate was painted with a separate paint system. The contract required that the surface be abrasive-blasted to meet the requirements of SSPC SP5, *White Metal Blast Cleaning*. A nonmetallic abrasive was to be used and the resulting surface profile was to be not less than 2 mils as measured by ASTM D 4417, *Method C (Replica Tape)*.

The paint application requirements called for "stripe" coat—a preliminary coat applied by brush to edges, corners, bolts, and other surface irregularities. The stripe coat was to be followed as quickly as possible by the application of the first coat of the paint system. Paint on all vertical and overhead surfaces was to be applied by airless spray. If excess moisture had condensed on these surfaces, they were to be wiped with clean rags before application of the coating. The floor of the structure was expected to be wet due to incomplete seal of the bulkhead. On this area the paint was to be applied with a roller; the area was to be rolled and backrolled in an effort to displace any standing or flowing water. Subsequent coats did not require the stripe coat. A target dry film thickness of 15 mils, as measured by ASTM D 1186, was required. Any areas with a measured coating thickness of less than 12 mils would require additional paint.

Gate 1 was to be painted with Reactic 1208 (gray), manufactured by the Imperial Division of Carboline (5644 Jefferson Highway, New Orleans, LA 70123-3791). This material was referred to as Coating 7 in the Phase I study and Coating 2 in the Phase II study. It performed well in the Phase I study but exhibited blistering under the exposure conditions used in the Phase II study. Reactic 1208 was included in the Phase III study to determine whether successful field application necessarily required a coating with superior laboratory results. The manufacturer offered assurances that the product would perform satisfactorily

in the actual field environment, and indicated that this coating is routinely applied without thinning, using brush, roller, or airless spray. The manufacturer stated that wet film thicknesses in excess of 10 mils would probably result in sagging.

Gate 2 was to be painted with Permox 9043 Type I wet process epoxy (gray), manufactured by Engineered Chemical Coatings (P. O. Box 33127, Decatur, GA 30033). This material was referred to as Coating 6 in the Phase I study and Coating 8 in the Phase II study. It was selected because of its high performance in the Phase II study. The manufacturer indicated that 10 percent thinning was usually necessary for airless spray, but thinning was usually not necessary for brush or roller application. Sagging could be expected at wet film thicknesses greater than 9 to 10 mils. Dry film thicknesses in excess of 12 mils per coat could create stresses within the coating and should be avoided. Product literature warned that lower temperatures and increased film thicknesses increase the dry-to-topcoat times published in the technical data sheet.

The contract, issued in September 1993, required the conduit liners and service gates be coated in place. The conduit liners were to be painted first, then the gates. High water conditions developed in the lake and the painters suspended their work in the conduit shortly after the first liner was sandblasted. The contractor requested and was allowed to continue work on the service gates in a dry location while waiting for the waters to recede. The gates were completed, but contract difficulties arose and the liners remained unpainted at the time of this report.

Application conditions at Gate 1 were high humidity and temperatures in the 50 to 52 °F range. Sagging created major difficulties, and long cure times created delays in the operation. Because the wet film thickness was well below the manufacturer's specified 10 mil sagging point the contractor sought additional guidance from the manufacturer. The manufacturer stated that although the application was within the temperature and humidity limits indicated in the company literature, the company had no actual field application experience under these conditions. In order to complete the application, the contractor was allowed to apply a significant amount of the coating by brush. The separate stripe coat required by the contract was not applied.

The application to Gate 2 was at the same location as Gate 1, however, the contractor was allowed to raise the temperature to approximately 68 °F. Application was by airless spray as required by the contract.

After being painted, the gates were returned to service. Service on the two gates was essentially equal, either both hanging in a high-humidity environment or both being immersed in fresh water. The first inspection took place after approximately 2 years of service.

After 2 years of service, Gate 1 had many areas of rust visible on complex areas of the gate. If the stripe coat had been applied as required by the contract, many of these coating failures would have been avoided. There were many areas with runs and sags. Some tear drops could be gouged off with a thumb nail. Some areas of relatively intact coating were extensively blistered. It was typical to find #4 blistering in areas where the coating thickness exceeded 20 mils. In areas where the coating was 12 to 16 mils, the coating had dense #5 blistering. Little blistering was noted in areas of less than 10 mils. One area of 6 mils appeared to be in perfect condition. All blisters were water-filled. Substrate under the blisters was bright.

After 2 years of service, the coating on Gate 2 had excellent adhesion and no blistering. The coating was well applied to corners and rivets, and very little rust was noted in these areas. Coating thickness ranged from 10 to 12 mils on the structural side of the gate and 18 to 20 mils on the smooth side. The gate was covered with a thick layer of black scum that was not noted on Gate 1. The scum was not identified, but it appeared to cause no adverse effect to the coating or to the operation of the structure.

Field Application II

A second contract, issued in September 1994, was awarded to apply the same coatings to an outlet structure at Stillhouse Hollow Lake, Army Engineer District Fort Worth. The structure to be coated consisted of two conduit liners extending through both the emergency gate and service gate areas. The combined areas of each liner had approximate dimensions of 6 x 12 x 12 ft and a total area of approximately 430 sq ft. Conditions of the conduit liners were consistent with each other, both in respect to the exposure conditions as well as the condition of the existing coatings. Service gate liner walls and ceiling were heavily rust-pitted and blistered in areas. Epoxy patch had been used to fill in the more heavily pitted areas. No flaking was noted in the existing vinyl coating. Seams, edges, and areas of seepage or weeping had created calcium deposits on the walls and ceiling of the liners. The liner walls and ceiling were damp or wet in areas of weeping. Hood areas were also rusted, pitted, and scaled. Paint coatings on the floor were thin, with paint missing over much of the area. Water on the floor

averaged 1.5 to 2 in. deep. Both emergency gate liners were in better condition than their corresponding service gate liners.

Work began on the west conduit liner on 15 November 1994, and continued through 1 December 1994. A total of 5450 lb of sand abrasive was used. Water leaking around the gate created quick flash rusting after sand blasting. Thick rubber tape and sand packing were used to reduce leakage, but neither worked as well as needed. Severe flash rusting was reblasted before painting. All old paint and corrosion products were removed to SSPC SP5 specifications but, by the time the paint could be applied, the steel had changed color from white metal to a dark gray on most walls, and black on the floor.

The west conduit area was coated with Reactic 1208. It was applied to the liner between 21 November and 12 December 1994. The paint was mixed according to the manufacturer's instructions. Thinning varied from 10 to 20 percent with Carboline T-76 reducer. The standard induction time of 30 minutes was observed. The paint was applied to wall and ceiling areas using conventional spray equipment. It was found that a wet film thickness of 8 mils could be applied on walls and ceiling without sagging. An attempt was made to apply the total thickness of >12 mils in a single coat. After overnight cure it was found that the material was dry to touch, but considerable sagging had occurred. Sags were sanded to a 5 to 8 mils thickness and the remainder of the coating thickness applied with rollers. The paint was hard to roll and adhere because of the moisture on the walls. Application to the floor area could not be accomplished by spray because of the flowing water, so the coating was simply poured onto the floor and spread with a roller. Hard pressure was required against the roller to get adhesion of the paint on the floor. The small area along the wall was coated using a brush. The on-site manufacturer's representative recommended a single 15 mil coating applied to the floor because long curing periods under water create difficulty in applying a second coat. According to the representative, the finish on the first coat would be too slick and hard for proper adhesion of the second coat. The dry film thickness varied from 12 to 20 mils on the walls and 16 to 30 mils on the floor.

Sandblasting on the east conduit liner was initiated on 2 December 1994 and continued through 8 December 1994. A total of 3300 lb of sand was used. The area was coated with Permox 9043. It was applied to the liner from 8 December 1994 through 13 December 1994. The paint was mixed according to the manufacturer's instructions, thinned approximately 15 percent, and applied with conventional spray to the ceiling and walls. The floor area was coated with roller and brush. There were a few problems in areas of seepage that resulted in

pinholes in some small areas and adhesion failure in larger seepage areas. Pinholes were most common on the ceiling area. The dry film thicknesses varied from 13 to 20 mils on the walls and ceiling, and 20 to 40 mils on the floor.

The contractor provided a record of the ambient conditions at the time of application and cost data for each application. These data are shown in Tables 7 and 8. Ambient conditions were considered equal in the two test areas.

After 9 months the performance of the coatings was observed. The Reactic in the west conduit was blistered in all areas. Blistering in the emergency liner area was mostly #6 dense while blistering in the service liner area was mostly #5 dense. A small loss of coating was noted, exposing some stainless steel that did not appear to have a satisfactory blast profile. The only areas of rust consisted of a 2–6 in. tall area extending several feet along the intersection of the floor with the wall (underwater application by brush) and a few areas of pinpoint rusting on the ceiling of the service liner.

After 9 months the Permax coating was in much better condition than the Reactic. The coating was hard and no blistering was noted. There was a line of rust about 1–1.5 in. tall and extending for about 3 feet on each side of the liner where the floor and the wall meet. This area was brush-applied and may not have sufficient thickness. Actual thickness measurements could not be taken at the time of the inspection because the area was underwater. There was also a small amount of rust where the steel joined the concrete and minor pin-point rusting on the ceiling. The remainder of the coating appeared durable and was offering complete protection.

Conclusions for Field Applications

Several conclusions were drawn for this phase of the study:

1. The blistering noted with Reactic 1208 reinforced the Phase II test results, but also indicated the failure was related to increased film thickness.
2. The good performance of the Permax 9043 also reinforced the Phase II test results.
3. The low temperatures in the conduit caused an increase in sagging, which should be addressed in any anticipated product specification.
4. Spray application was practical on vertical surfaces that were damp but where the water could flow off the surface.

Table 7. Record of environmental conditions during Phase III.

Date	15 Nov		16 Nov		17 Nov		18 Nov		21 Nov		28 Nov		1 Dec		2 Dec	
	1030	1430	1100	1545	1000	1430	930	1330	1000	1400	1030	1430	1600	1100	1500	1500
Data Recorded																
Surface Temp, deg F	56	56	56	58	56	57	54	55	56	58	55	55	52	52	50	50
Ambient Temp, deg F	62	62	60	63	64	62	62	64	62	95	59	62	60	60	62	62
Relative Humidity, %	84	84	75	85	84	95	90	89	65	75	60	70	75	70	82	82
Dew Point, deg F	52	52	46	59	61	57	59	61	52	55	46	53	54	51	56	56

Date	5 Dec		7 Dec		8 Dec		9 Dec		12 Dec		13 Dec	
	1100	1500	0930	1330	0930	1330	0930	1330	1000	1300	0930	0930
Data Recorded												
Surface Temp, deg F	56	56	55	63	55	54	52	52	52	57	52	52
Ambient Temp, deg F	62	63	63	63	62	61	55	55	55	57	55	55
Relative Humidity, %	90	95	95	80	75	90	70	65	60	75	65	65
Dew Point, deg F	58	62	62	55	54	58	46	42	42	47	42	42

Table 8. Cost of paint systems for Phase III.

	<u>REACTIC</u>	<u>PERMITE</u>
SET UP JOB (Labor, Equipment, Supplies)	\$2343.96	\$2343.96
PREPARE SURFACE (Labor, Sand, Equipment)	\$1836.20	\$1120.26
PAINT SURFACE (Labor, Paint, Equipment)	\$1464.43	\$1159.97
TAKE DOWN JOB (Labor, Equipment)	\$1662.11	\$1662.11
MISCELLANEOUS (Vehicles, Extra Supplies, Etc.)	\$4313.00	\$3213.00
TOTAL COSTS	\$11619.70	\$9499.30
COST PER SQ FT	\$26.95	\$22.04

5. Pinholes developed on the ceiling areas where water hung in droplets. Rolling or brushing may have been a more effective method of application in this area.
6. Products could be applied to floor areas that were underwater by using a roller in a single-coat application.
7. Application by brush may be the only practical method for applying a stripe coat, but should not be used for larger areas where rollers or spray equipment could be used to apply a more uniform coating.

5 Summary, Conclusions, and Recommendations

Summary

In Phase I a number of paint systems were subjected to a series of tests, primarily to evaluate the test procedures. It was determined that coatings do exist which will adhere to wet or damp steel in a condensing environment. It was further determined that the most demanding condition being evaluated was the requirement that the coating fully cure in a condensing environment. Curing in an environment having only low temperature and high humidity had little if any effect on most of the coatings initially tested.

In Phase II, 12 paint systems were applied to wet metal and then subjected either to immersion or condensation conditions. Evaluation of these systems after 2 weeks of exposure determined that six of the systems being tested would not be recommended due to their immediate failure, signs of adhesion failure, or degradation of the coating system. The other six systems were divided into two groups: (1) two coating systems that passed all of the testing with little or no change, thus putting them in the acceptable category, and (2) four systems that exhibited some test results that may or may not affect the performance of the coating systems under the field conditions. Continued observation of the immersed panels after 18 months did not reveal any coating failures that were not predicted by initial evaluations.

Although most of the systems tested were epoxies, the generic paint type did not appear to affect the outcome of the testing. Many of the epoxies performed well while others failed. Just as the type of paint did not appear to determine the outcome, neither did the number of coats applied. Five of the tested systems were single-coat products; one of these fell into the group of highest performance, one into the intermediate group, and three into the group that would not be recommended for this type of service. The performance appeared to be a function of the paint's ability to cover a wet surface and cure under damp conditions, regardless of paint type or number of coats.

In Phase III, two coatings were applied to field structures. The applications revealed a number of problems. Sagging problems were encountered, and may have been amplified by the low temperatures in the field. Spray application was practical on walls, but pinhole failures on ceiling areas may be attributed to the inability of these coatings to adequately displace water when sprayed on ceilings. The blistering noted on one of the Phase III coatings had also been noted in Phase II. The greatest amount of corrosion noted was in areas where the coating was brush-applied. Uniform thickness is difficult to obtain with brush application of heavy-bodied coatings, and it is thought that the failure is due to insufficient thickness rather than method of application.

Conclusions and Recommendations

The research has shown that coatings are available that will adhere to an abrasive-blasted steel surface that is either damp or wet at the time of application. One such coating is continuing to provide a satisfactory level of corrosion protection on a gate after 2 years, and on a conduit liner after 1.5 years. However, this conclusion does not imply that the level of protection is equal to that of a high-performance coating applied under dry conditions. Even the best of the coatings tested allowed some rust to occur in areas where the coating was thin or its application did not completely displace the water. Therefore, it is recommended that these coatings only be specified in areas where it is not possible to achieve a completely dry surface.

The laboratory test methods used to evaluate the products provided an indication of potential performance, but results from the field applications indicated that some tests should be modified in order to identify specific problem areas:

1. In the field, application by roller appeared to be the most practical method in areas where surfaces had a significant amount of standing or running water. Therefore, it is recommended that laboratory testing include roller application to wet panels.
2. The low temperatures encountered in the field application aggravated sagging problems and curing times. Therefore, it is recommended that the laboratory application and cure testing be conducted at a temperature similar to that encountered in the field. The lower-temperature test conditions will require lengthening the immersion testing in order that adhesion loss and blistering results may be observed.

Appendix A: Draft Commercial Item Description

NOTE: This draft dated March 24, 1998 prepared by DOD-CE has not been approved and is subject to modification. DO NOT USE FOR ACQUISITION *

[METRIC]

A-A-XXX

March 24, 1998

COMMERCIAL ITEM DESCRIPTION PAINT (FOR APPLICATION TO WET SURFACES)

The General Services Administration has authorized the use of this commercial item description by all federal agencies.

1. SCOPE. This commercial item description covers a liquid paint for application to an abrasive-blasted steel surface that is wet with condensation or flowing water at the time of application. The paint is designed for long-term corrosion protection of the steel in the condensing or immersion environment.
2. SALIENT CHARACTERISTICS. The paint shall meet the following test requirements:
 - 2.1 Test Panel Preparation: Paint for testing shall be applied to steel test panels that are grit-blasted to meet the SSPC SP5 surface preparation grade and have an anchor profile of 40–60 microns as tested by ASTM D 4417, Method C. Duplicate panels shall be laid in a pan of water that covers the panels to a minimum depth of 2.5 cm. In this position the panels shall be coated using a paint roller. Another duplicate set of panels shall be removed from water immersion, placed in a vertical position, and coated while still wet using airless spray. Manufacturer's published guidance on mixing, thinning, induction time, and recoat time shall be followed. Application shall be evaluated as required below. Immediately after

*Beneficial comments, recommendations, additions, deletions, clarifications, etc. and any other data which may improve this document should be sent to: General Services Administration, GSA Center (9FTE-10), Auburn, Washington 98001.

application all panels shall be immersed vertically in distilled water maintained at 15 °C and allowed to cure. Coating thickness shall be a minimum of 300 microns. If additional coats are necessary to meet this requirement, they shall be applied in the shortest recoat time recommended by the manufacturer and in the same manner as the initial coat. After the final coat has cured 48 hours, each panel shall be tested for completeness of cure, scribed with a 7cm diagonal line to the substrate, and returned to immersion for 28 days.

2.2 Evaluation of Application: The spray-applied coating shall be free of pinholes and holidays. The roller-applied coating shall be easily applied without need for excessive backrolling to produce adhesion to the substrate or previous coat. The material shall not excessively float or disperse in the water. After cure the applied coating shall be free of runs, sags, voids or other defects.

2.3 Evaluation of Cure: After the final coat has cured 48 hours the coating shall have a minimum completeness of cure rating of 3 when tested according to ASTM D 4752.

2.4 Evaluation of Performance: After the 28-day immersion all panels shall be removed and evaluated for evidence of poor performance. The coating shall have a blister rating of 10 when evaluated according to ASTM D 714. The coating shall have a rust rating of 10 when evaluated according to ASTM D 610. The evaluation shall exclude rust associated with edges and the score on each panel. The coating shall have an adhesion rating of 4 or greater when tested according to ASTM D 3359, Method A. The coating shall be probed with a sharp knife along the score. Evidence of decreased adhesion to the substrate or poor intercoat adhesion extending farther than 2mm from the scribe shall be considered failure of the coating.

3. QUALITY ASSURANCE PROVISIONS.

3.1 Manufacturer Certification. The manufacturer shall certify and maintain substantiating evidence that the product offered meets the salient characteristics of this Commercial Item Description, and that the product conforms to the producer's own specifications, standards, and quality assurance practices. The government reserves the right to require proof of such conformance prior to first delivery and thereafter as may be otherwise provided for under the provisions of the contract.

3.2 Market Acceptability. The following market acceptability criteria are necessary to document the quality of the product to be provided under this CID.

3.2.1 The company producing the item must have been producing a product meeting the requirements of this CID for at least 2 years.

3.2.2 The company must have sold 500 gallons meeting this CID in the commercial marketplace over the past 2 years.

4. NOTES. The following coatings have been tested and found to meet the requirements of this document:

<u>PRODUCT*</u>	<u>MANUFACTURER</u>
Interzon 954HS	Porter International 1301 W. Kentucky St. Louisville, KY 40210
Alocit Aquacoat 28.15	The Warfield Company, INC 1005 Sussex Boulevard Broomall, PA 19008
Permox 9043	The Permite Corporation 5239 Brer Rabbit Road Stone Mountain, GA 20083

5. SOURCE OF DOCUMENTS.

5.1 The Steel Structures Painting Council (SSPC) specifications for surface preparation are available from SSPC, 4516 Henry St., Pittsburgh, PA 15213-3728.

5.2 ASTM Standards are available from the American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.

MILITARY INTERESTS:

Preparing Activity: GSA-FSS

*Note: These three products performed very well in the research conducted. It is thought that they will meet the requirements of this draft document. Formal testing is not yet complete.

Appendix B: Products Used in This Study

<u>Manufacturer</u>	<u>Product name</u>	<u>Phase I</u>	<u>Phase II</u>
Con-lux Coatings Inc. P. O. Box 847 Edison, NJ 08818-0847	Aquathane 6970 Aquathane 6960		5 5
Devoe Coatings P. O. Box 7600 Louisville, KY 40257-0600	Bar-Rust 235	2	1,6
Edison Chemical Systems, Inc. 25 Grant Street Waterbury, CT 06704	Aquepoxy250 HD	1	
Engineered Technical Coatings P. O. Box 33127 Decatur, GA 30033	Permox 9043	6	8
E. I. DuPont De Nemours & Co. 1007 Market St. Willmington, DE 19898			25P Epoxy Mastic 9
Hempel 6901 Cavalcade Houston, TX 77028	Hempadur 4515 Hempadur 1557		3,4 4
Imperial Specialty Coatings Division of Carboline 5466 Jefferson Highway New Orleans, LA 70123-5189	Reactic # 1208	7	2
International Paint 2270 Morris Ave. Union, NJ 07083	Icoguard		11

Porter International 1301 W. Kentucky St. Louisville, KY 40210	Interzon 954HS	12
PPG One PPG Pl Pittsburgh, PA 15272	Low Temperature mastic Low VOC Pitthane	7 7
Sherwin Williams Co. 101 Prospect Ave Cleveland, OH 44115	Surface Tolerant Epoxy Primer	8
Valspar Corporation 1410 Severna St. Baltimore, MD 21230	Valmastic WTC 600 Wetsall 3241 Primer	3 4
Wasser High Tech Coatings 8041 S. 228 th St. Kent, WA 98032	MC Ferrox B	5

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13. ABSTRACT (Maximum 200 words)

The Corps of Engineers is responsible for maintaining numerous steel structures that are subjected to conditions of constant condensation inside locks and dams. The surfaces of these structures normally can be blast-cleaned to a white metal grade, but condensation and/or water leaking around seals immediately make the surfaces too wet for the application of many coatings. The coatings industry has recently developed and marketed new coatings that adhere to wet or damp steel. In this study a number of these products were evaluated, both in the laboratory and on structures in the field. Results indicate that some of these coatings hold promise for long-term corrosion protection. Based on the results, a draft Commercial Item Description is included to specify durable coatings for wet and damp steel surfaces.

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